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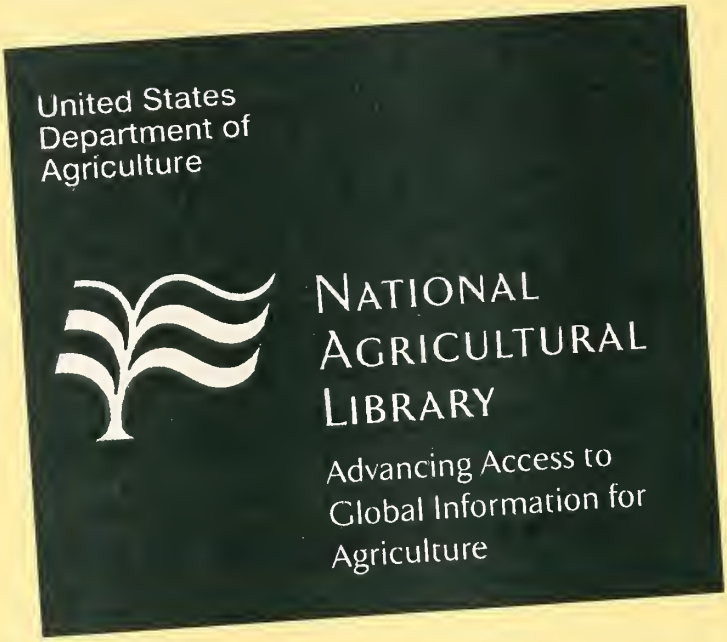
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SURFACE RUNOFF AND EROSION IN THE LOWER CHAPARRAL ZONE - ARIZONA

by

Lowell R. Rich, Hydraulic Engineer

Rocky Mountain Forest and Range Experiment Station[1/]

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INTRODUCTION

Within the lower chaparral zone of Arizona, watershed management is concerned not only with water supplies, but also with maintenance of an adequate plant cover to control erosion.

This paper discusses the effect of recovery of vegetation, mechanical stabilization, and cover changes on storm runoff and sediment yields from nine small watersheds located on granitic soils in the lower chaparral zone.

THE LOWER CHAPARRAL ZONE

The lower chaparral zone in Arizona is characterized by low rainfall and warm climate. Soils on several hundred thousand acres in central and southwestern Arizona are derived from granite rocks. Many granitic areas have a chaparral plant cover (fig. 1) and are adjacent to and a major source of sediment to streams and irrigation reservoirs. For example, a total of 101,000 acre-feet of sediment, predominantly coarse grained, accumulated in Roosevelt Reservoir between 1909 and 1925. Much of the drainage area immediately above Roosevelt Dam is covered by loosely consolidated alluvial deposits or disintegrated granites. The latter are prolific sources of coarse-grained sediment under present erosional conditions.[2/] The coarse-grained sediment in Roosevelt Reservoir together with erosion of the granitic areas indicated the need for detailed studies on granitic watersheds in the lower chaparral zone. Consequently an area for study was selected near the divide between Pinal and Pinto Creeks, about 15 miles above Roosevelt Reservoir.

EXPERIMENTAL AREA

The experimental watersheds are located between Globe and Roosevelt, Arizona, at the summit of a divide and are often referred to as the Summit watersheds. The arrangement of experimental watersheds is shown by figure 2. Four south-facing watersheds (Nos. 1, 2, 3, and 4) and three north-facing watersheds (Nos. 5, 6, and 7) were fenced to exclude livestock in 1925. One south-facing watershed (No. 8) and one north-facing watershed (No. 9) were not fenced. Size, aspect, and treatment of watersheds are summarized in table 1. Elevations range from 3,636 to 3,905 feet. Precipitation averages about 15 inches annually.

2/ Eakin, Henry M. Silting of reservoirs. U. S. Dept. Agr. Tech. Bul. 524, 142 pp., illus. 1936. (Rev. 1939 by Carl B. Brown, 168 pp.)

Figure 1. --Granitic soil areas in Arizona in relation to major drainages and distribution of chaparral.

Topographically, the experimental watersheds are similar to many granitic areas of central and southwestern Arizona. Low ridges alternate with shallow depressions that drain into wide flat channels below the watersheds. Slopes on the watersheds average 25 to 35 percent.

Vegetation represents both desert grassland and chaparral. South-facing slopes are occupied mostly by shrubs and perennial grasses. North slopes are covered almost entirely by close-growing shrubs, principally shrub live oak. 3/

3/ Common and botanical names of plants are given in the appendix.

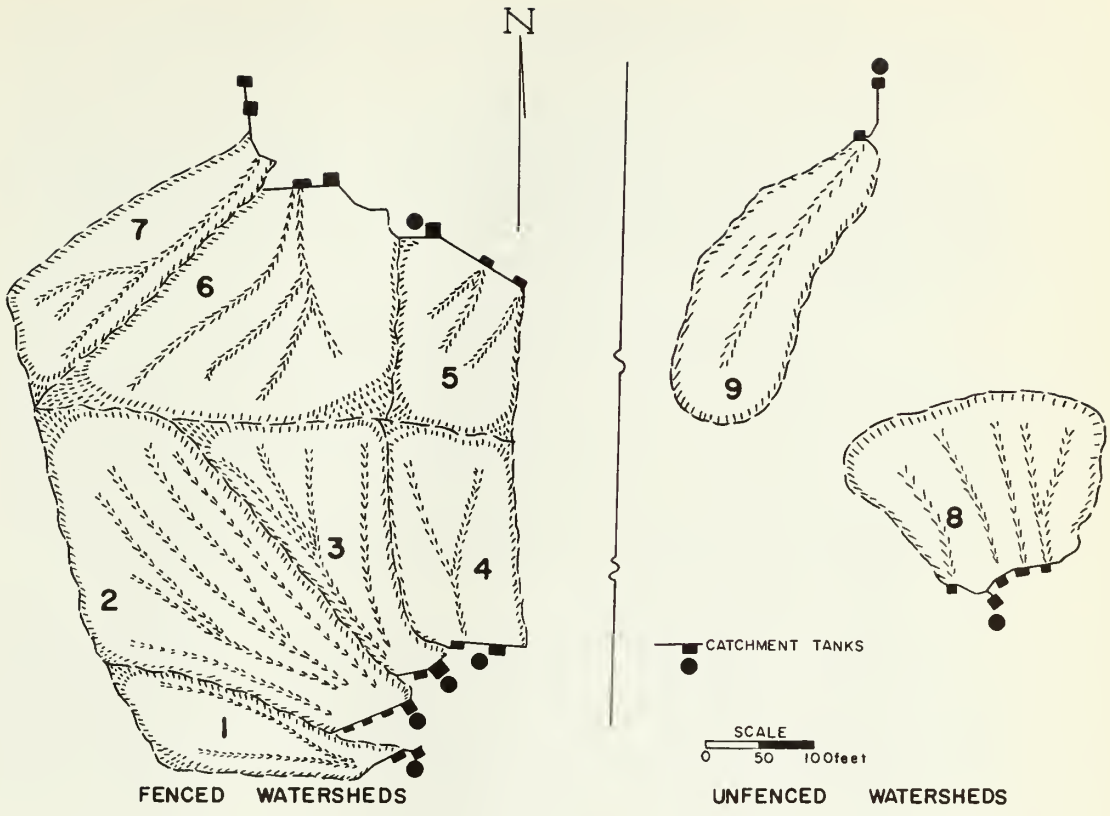

Figure 2. --Size, shape, and arrangement of the experimental watersheds.

Table 1. --Size, aspect, and treatments of experimental watersheds

Watershed Number	Treatments	Aspect	Size
			(Acres)
1	Fenced 1925, ungrazed, seeded to grass 1953[1]	South	0.37
4	Fenced 1925, ungrazed, seeded to grass 1953[1]	South	.49
5	Fenced 1925, ungrazed, seeded to grass 1953[1]	North	.43
7	Fenced 1925, ungrazed, seeded to grass 1953[1]	North	.49
3	Fenced 1925, ungrazed, hardware cloth checks placed on slopes in 1934	South	.59
2	Fenced 1925, ungrazed	South	1.23
6	Fenced 1925, ungrazed	North	1.05
8	Unfenced, open to grazing	South	.80
9	Unfenced, open to grazing	North	.54

[1] Before grass was seeded, woody plant cover was cut, roots grubbed out, gully banks sloped, and gullies filled with cut plant material.

Soils on ridges may be less than 2 feet to bedrock, while downslope soils may reach a depth of 6 to 7 feet. In 1925, there was an intricate system of gullies throughout the watersheds, with deepest gullies on north-facing watersheds.

The coarse-grained granite of the experimental watersheds is probably a continuation of "Ruin" granite mapped by Ransome [4/] along the northern edge of the Globe Quadrangle, about 4 miles to the north. This granite is uniformly of coarse-grained porphyritic texture and has a tendency to form broad basins or valleys of erosion.

TREATMENTS AND MEASUREMENTS

Experiments were designed to determine the influence of land management practices on sediment and storm runoff. Treatments included: (1) Exclusion of livestock grazing on seven watersheds from 1925 to 1953, (2) winter grazing (January to April) on two watersheds between 1928 and 1934, (3) installation of hardware cloth checks on one watershed in 1934, and (4) grubbing brush, sloping gullies, and planting of perennial grass on four watersheds in 1953.

In 1925: (1) Profiles from permanent bench marks to sample soil moved on cuts and fills, (2) quadrats to measure plant cover, and (3) gages to record precipitation were established. Catchment tanks were installed in 1931 to measure storm runoff and sediment. Air temperatures were recorded in 1934 and 1935. Vegetation transects were established and measured in the fenced area in 1954 to supplement the original quadrats.

Profile measurements and quadrat chartings were repeated at intervals varying from 6 months to 7 years. Storm runoff and resulting sediment were measured volumetrically after each storm between 1932 and 1941. Between 1941 and 1953 storm runoff was not measured. Sediment that accumulated after 1941 was measured for watershed numbers 1, 3, 4, 5, 8, and 9 in 1947. Records were lost from 1941 to 1953 when catchment tanks overflowed on watershed numbers 2, 6, and 7. Measurements of sediment were continued twice a year (June 1 and October 1) after that date. Measurements of storm runoff and sediment after each storm on all watersheds were reactivated in 1953.

The experimental design compares storm runoff amounts and sediment rates for treated and untreated watersheds. Between 1932 and 1941, differences between livestock exclusion and winter grazing were compared. From 1953 to 1959 the results of grubbing brush, filling gullies, and seeding grass on four watersheds were measured. On one watershed small checks of hardware cloth were placed on slopes in 1934; this treatment was compared with an adjacent control watershed. During the periods when storm runoff was measured, areal average infiltration capacities were computed from precipitation intensity and storm-runoff quantities, and comparisons between treatments were made.

4/ Ransome, Frederick L. Geology of the Globe Copper District, Arizona. U. S. Geol. Survey Prof. Paper 12, 168 pp., 1903.

PRECIPITATION AND TEMPERATURE

Precipitation for 29 years, 1927-42 and 1946-59 averaged 15.16 inches annually (table 6, appendix), 9.15 inches winter (October through May), and 6.01 inches summer (June through September). During this 29-year period there were 1,153 days with a trace or more of precipitation. Only 5 percent of these days had rain totaling an inch or more and 61 percent had less than 0.13 inch.

Most precipitation falls during the months of December, January, February, March, July, and August. Long dry periods are usual. On the average 158 days per year were grouped into 30 consecutive days or longer without a rain of 0.15 inch or more (fig. 3).

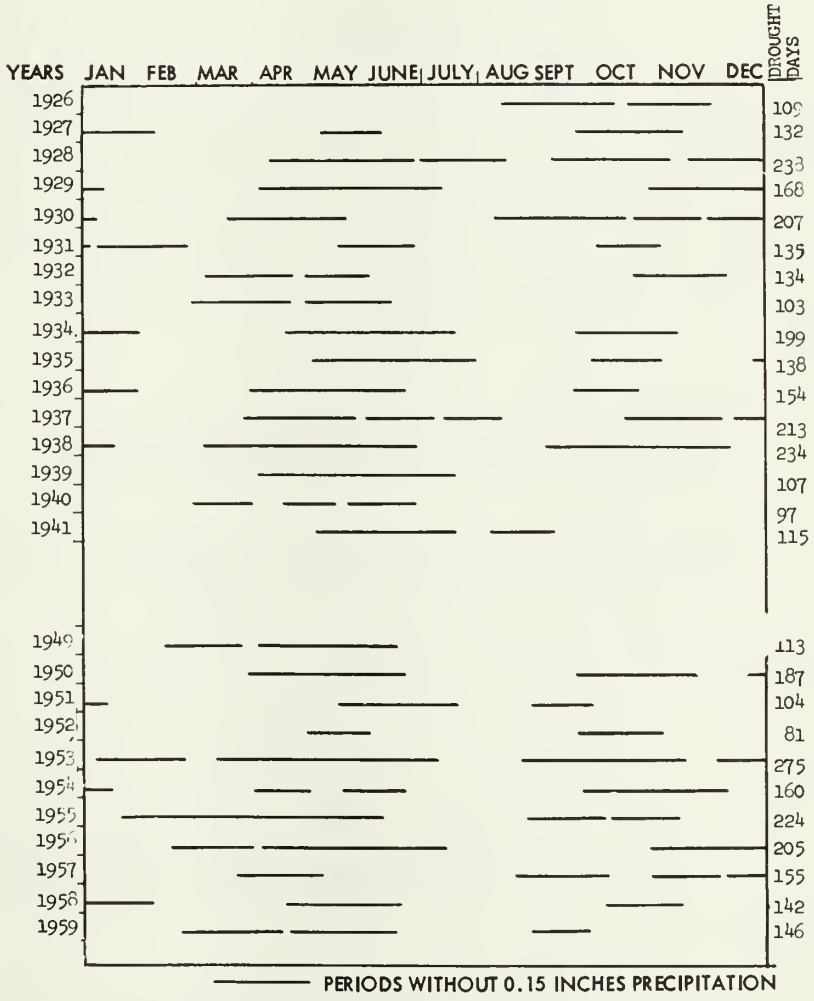

Figure 3.--Periods of 30 days or longer with less than 0.15 inch of precipitation per day at Summit watersheds.

Storm intensity from some of the highest intensity storms were:

Date	For 5 minutes	For 15 minutes	For 60 minutes
	(Inches per hour)		
July 19, 1951	4.20	3.60	1.80
August 5, 1933	3.60	2.80	2.80
August 1, 1935	3.30	3.08	2.80
July 1, 1959	4.20	3.20	1.60

In figure 4, daily distribution of precipitation is illustrated for the maximum year (1940-41), minimum year (1933-34), and a near-average year (1952-53).

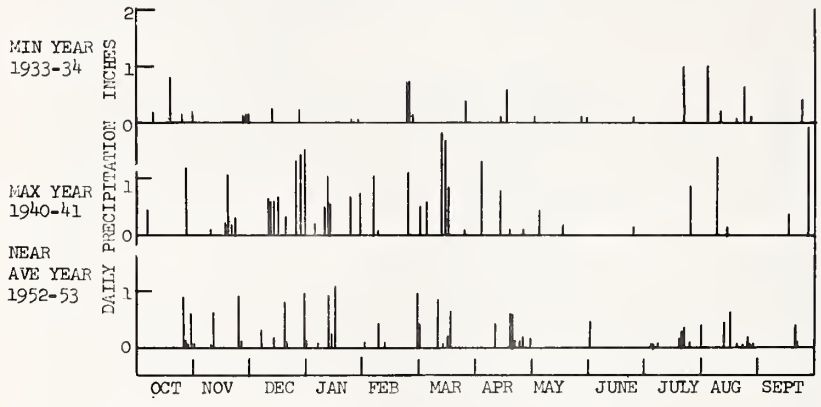

Figure 4. --Distribution of daily precipitation for maximum year, minimum year, and a near-average (annual total) year.

Average yearly temperature is about 63°F. Average mean monthly temperatures for 1937-38 were:

Month	Temperature (°F.)	Month	Temperature (°F.)
October	68.2	May	70.9
November	50.6	June	79.4
December	46.4	July	83.8
January	41.4	August	82.2
February	47.1	September	78.3
March	50.7		
April	61.2	Average annual	63.4

Low rainfall, prolonged drought periods, and high temperature limit growth and establishment of vegetation.

PROTECTION PERIOD, 1925-53

VEGETATION CHANGES

At the time of fencing in 1925, the cover on south-facing slopes was principally old jojoba, young catclaw acacia, and mescat acacia. Cover on north-facing slopes was almost entirely shrub live oak. There were a few clumps of native perennial grasses on south aspects, but almost none on north aspects. There was soil movement in spaces between shrubs on both aspects.

Ten meter-square quadrats were located on the fenced watersheds in June 1926. Until 1936, only basal area of shrubs was charted. After 1936, measurements included crown spread. The quadrats, recharted intermittently between 1926 and 1947, provide the record for density changes of perennial grasses and small shrubs in the fenced area. A record of large shrubs was not maintained.

Perennial Grasses

Average basal area of perennial grasses (fig. 5) on the quadrats increased to December 1930 (highest recorded); decreased to November 1935 (lowest recorded); and increased again until 1947. Except for the large increases in the 1930-32 period, average basal area shows little net change over the 1926-47 period. Variations in the basal area of grasses and amount of summer or winter precipitation are shown in figure 5. Because of limited plant measurements, cover trend cannot be compared adequately with precipitation trends.

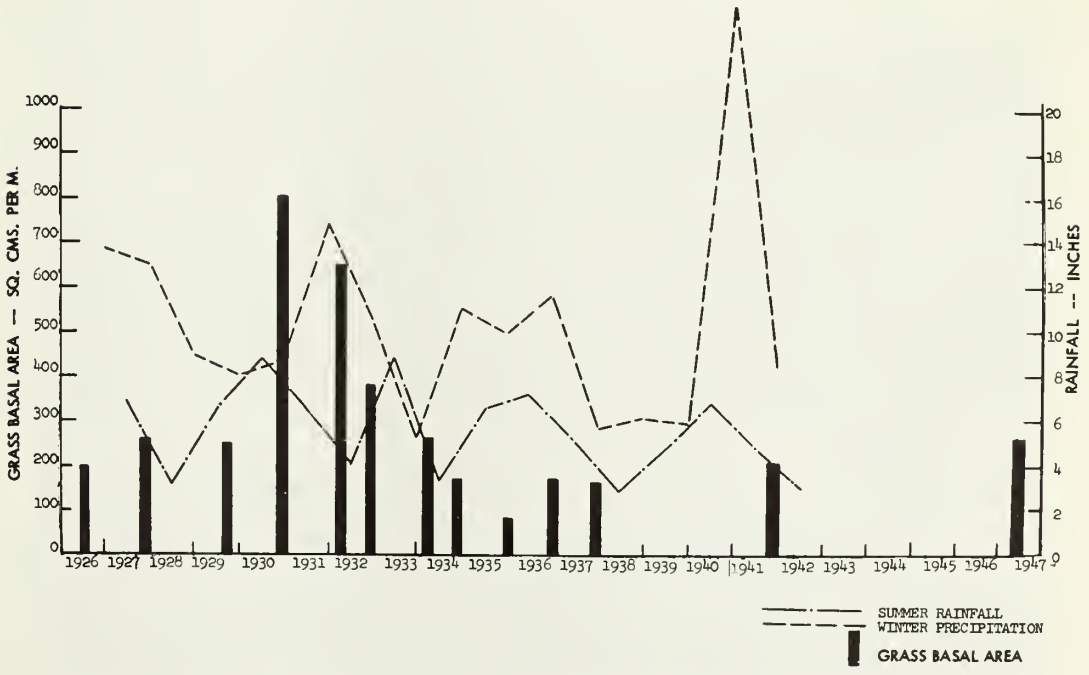

Figure 5. --Average basal area of perennial grass on 10 meter-square quadrats compared with summer and winter precipitation on the fenced watersheds.

Side-oats grama, three-awn grasses, sprucetop grama, and desert needlegrass were the main perennial grasses on the quadrats. For most chartings, side-oats grama constituted more than half of the total.

Both drought and site deterioration probably contributed to loss in grass after 1930. In one instance a gully practically eliminated a quadrat. With regard to drought, most of the grass in all quadrats died during 1934 and had not become reestablished on two quadrats by 1947.

These vegetation measurements illustrate the need for sampling over a relatively long period because of wide fluctuations in basal area of perennial grasses in semiarid areas.

Shrubs

The establishment of quadrats in the unfenced area (watershed Nos. 8 and 9) and measurements of small shrub crowns permit comparison between the fenced and the unfenced area from 1936 to 1947. Crown area of shrubs remained almost exactly the same in both the fenced and unfenced areas, as did basal area of perennial grasses. Wright buckwheat constituted about three-fourths of the total shrub area in the quadrats. False-mesquite, littleleaf krameria, mescat acacia, and broom snakeweed made up the balance.

Photographic Record

Repeat photographs in 1953 of pictures taken in 1935 and 1936 of watershed numbers 1 and 2 (figs. 6 and 7), watershed numbers 3 and 4 (figs. 8 and 9), and watershed numbers 5 and 6 (figs. 10 and 11) show only small changes in the overall character of vegetation. In general, shrubs increased in size and thickened some in the lower part of watershed number 2 (fig. 9). The saguaro cactus below the catchment tank on watershed number 4 made considerable growth. All photographs taken in 1935, 1936, and 1953 show a lack of plant cover between shrubs.

Winter Grazing

Watershed numbers 4 and 5 were conservatively grazed in winter between 1928 and 1934. While not shown separately on figure 5, plant cover on these watersheds followed the same general pattern as on the ungrazed watersheds. After 1934 all watersheds in the fenced area were protected from cattle grazing.

PROFILE MEASUREMENTS OF EROSION

Based on individual profile measurements, soil loss averaged 2.67 inches for all watersheds between 1926 and 1949. This loss (based on 85 pounds per cubic foot for eroded material) approximates 11,000 tons per square mile annually. The highest rate, 27,000 tons per square mile per year, was recorded between August 1926 and January 1928, the lowest, 4,260 tons per square mile annually, between April 1942 and September 1949. Soil losses, measured by profiles, are higher than those measured by catchment tanks due in part to soil being moved from profile lines but being deposited before reaching catchment tanks, and to too few profiles to reliably sample the watersheds.

Figure 6. --Watershed numbers 1 and 2 in 1935.

Figure 7. --Watershed numbers 1 and 2 in 1953.

Figure 8. --Watershed numbers 2, 3, and 4 in 1935.

Figure 9. --Watershed numbers 2, 3, and 4 in June 1953.

Figure 10. --Watershed number 5 and part of number 6 in 1936.

Figure 11. --Watershed numbers 5 and 6 in 1953.

Individual profiles illustrate how erosion took place on the experimental watersheds. Five profile lines, which follow a gully system of watershed number 2 from top to bottom, are shown in figure 12. Profile number 2 is about 50 feet downslope from the top of the watershed, number 4 is 110 feet, number 7 is 155 feet, number 9 is 225 feet, and number 25 is 325 feet downslope. Near the top of the watershed, shallow soils and frequent bedrock outcrops prevent formation of deep gullies. Nevertheless, surface runoff concentrates between shrubs and clumps of grass. In the middle of the slopes (station No. 9), soils are deeper and gullies are largest. Near the bottom of the slopes, the flatter gradient and the stabilizing effect of catchment troughs and tanks prevent formation of large and deep gullies.

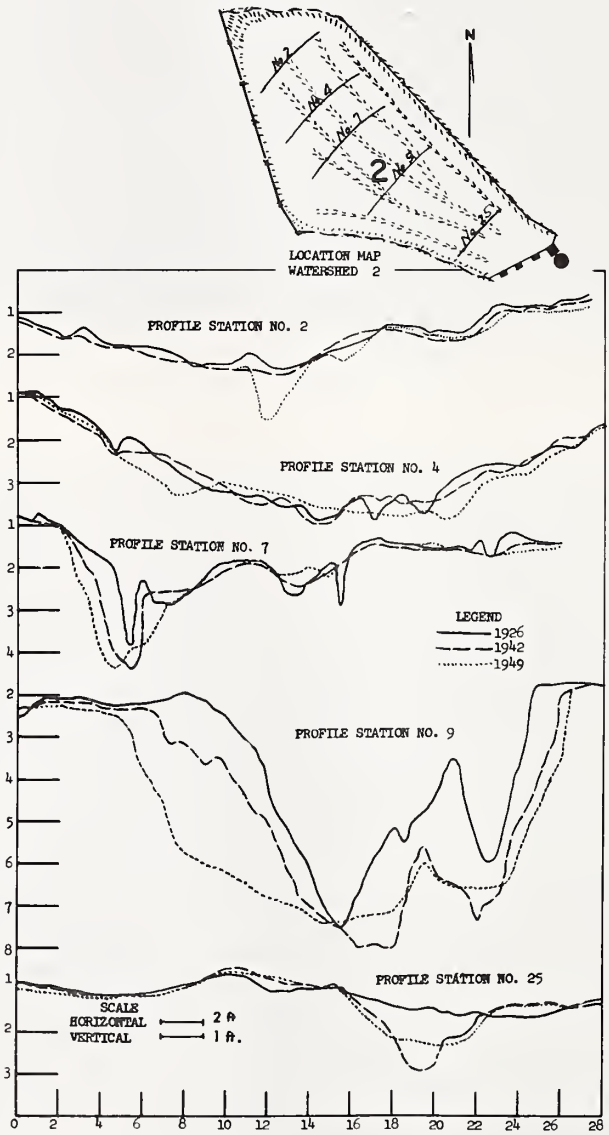

Figure 12. --Profiles that follow a gully system from top to bottom of watershed number 2.

Some profiles in the central parts of watersheds crossed gullies that showed greater loss in cross section during measurements than had occurred previously. For example, in 1926, station number 59 in watershed number 9 (fig. 13) intersected a V-shaped gully, $5\frac{1}{2}$ feet deep and 9 feet wide at the top, approximately 26 square feet in cross section. By 1942, erosion had enlarged it to a U-shaped gully, 6 feet deep (deepening stopped by bedrock), 15 feet wide at the top, and approximately 57 square feet in cross section. Gullies such as those measured at stations 9 and 59, once established, continued to enlarge. This unstable condition has probably been a major factor in reducing establishment of vegetation.

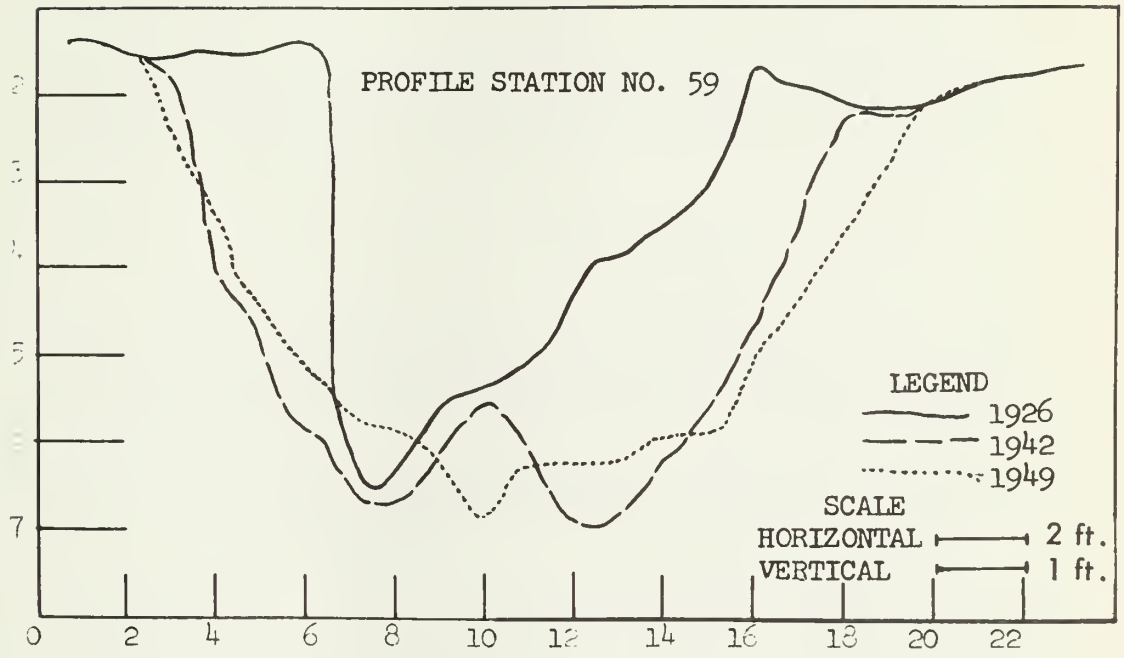

Figure 13.--Profile station number 59 in watershed number 9 showing outlines of gully in 1926, 1942, and 1949.

CATCHMENT TANK MEASUREMENTS OF SEDIMENT

Between 1932 and 1942, sediment trapped from the 5.99 acres of the nine watersheds averaged 5,649 tons per square mile per year. The rates varied from 2,164 tons per square mile per year from watershed number 4 to 12,785 tons from watershed number 9. Sediment measurements are tabulated in table 7, appendix.

Nearly 83 percent of the total sediment for the 10-year period was moved by summer storms. The 13 storms that yielded 70 percent of the summer storm runoff moved 73 percent of the total sediment. Storm runoff during the winter of 1940-41 (60 percent of the 10-year total) moved 56 percent of the total winter sediment (table 8, appendix).

Sediment rates for 1950-51, among the highest measured, were associated with the highest summer rainfall recorded, 10.29 inches, of which 6.91 inches fell during August. Because of heavy scouring of gullies and channels in this year, sediment rates for the following years were probably lower than normal.

Average annual sediment rates for the comparative periods 1942-53 and 1950-51 for six watersheds were:

Watershed number	Average annual sediment rates (Tons per square mile per year)	
	1942-53	1950-51
1	2,366	12,629
3	573	4,214
4	2,401	8,561
5	1,392	4,195
8	2,080	10,385
9	4,902	19,159

PRECIPITATION AND STORM RUNOFF

Measured storm runoff from the experimental watersheds, 1932-41, average 3.2 percent (1.6 to 6.4 percent) of the annual rainfall as follows:

Watershed number	Average annual storm runoff	
	(Inches)	(Percent of precipitation)
1	0.896	5.7
2	.396	2.5
3	.260	1.6
4	.550	3.5
5	.482	2.9
6	.273	1.6
7	.394	2.3
8	1.064	6.4
9	.667	4.0

Storm runoff was confined to short periods following precipitation. Channels were dry the rest of the year.

Storm runoff varied more than precipitation. For example, during the maximum year, 1940-41, precipitation was almost double average, but storm

runoff was nearly three times average. Precipitation during the minimum year, 1938-39, was 67 percent of average, but runoff was only 19 percent of average (table 9, appendix).

Summer rains produced 63 percent of the storm runoff on the experimental watersheds. Nearly all summer storm runoff resulted from intense thunderstorms. The 13 most intense summer storms in the period 1932-41 yielded 69 percent of the total storm runoff, although these storms made up only 33 percent of the total rainfall (table 10, appendix).

High-intensity thunderstorms are common on the experimental watersheds during summer. In the 10-year period, 12 individual storms exceeded 0.86 inch. Nine of these storms had 15-minute intensities of 1.40 to 3.08 inches per hour; six storms showed 30-minute intensities of 1.19 to 2.80 inches per hour.

Variations in average annual precipitation on the study area compare closely with longer records at nearby stations. Extremes sampled, such as the wet year of 1940-41 and the drought year of 1933-34, approach the extremes associated with this region.

EFFECT OF PROTECTION

At the start of this study the watersheds were not reacting alike. Both storm runoff and sediment production were consistently higher from some watersheds. When storm runoff and sediment production were used as measures, variance analysis gave highly significant "F" values (3.36 for storm runoff and 6.78 for sediment). This indicated the watersheds were not reacting in the same way to precipitation. This is not unusual because adjacent watersheds often vary because of inherent differences in watershed characteristics. The statistical analysis method of covariance was used to learn whether watershed differences were due to protection or grazing.

If either protection or winter grazing had influenced storm runoff or sediment production, a definite trend should be evident. To check for trends, that is, whether there was an increase or a decrease in storm runoff and sediment production from the protected watersheds compared to the unprotected watershed, annual data from the nine watersheds were analyzed by covariance. Years were used as the independent variable and storm runoff (table 9, appendix) and sediment rates (table 7, appendix) as the dependent variables. In both analyses the mean square for differences among the regressions for individual watersheds was less than the error term, indicating that the average regression for all watersheds was the best estimate of population regression. Since the regressions for the individual watersheds did not differ, it was evident that no significant change within the limits of experimentation resulted from either protection from grazing or from winter grazing. This also indicated that the period 1931-41 could be used as the calibration period for subsequent treatments.

EFFECT OF HARDWARE-CLOTH CHECKS

Watershed number 3 was treated in 1934 by placing low hardware-cloth check dams on contour lines, about 3 feet apart, with the top of one strip of

hardware cloth level with the bottom of the one above (fig. 14). Sediment rates were decreased nearly 93 percent, as shown by the following tabulation:

Characteristics	Before treatment	After treatment
Period	1932-34	1935-41
Annual rainfall (inches)	15.42	15.94
Eroded material (tons/sq.mi./yr.)	6,476	479

This treatment effectively decreased total soil loss from the watershed, but did not stop the shifting of soil between the checks (figs. 14 and 15). Increase in vegetation, as measured by quadrats, was negligible.

STABILIZATION BY CHANGING COVER, 1953-59

Four watersheds (Nos. 1, 4, 5, and 7) were seeded to Boer and Lehmann lovegrasses in June 1953, after native shrubs had been grubbed and spread as a mulch that shaded approximately half the ground. In addition, gully banks were sloped to prevent sloughing and to provide a stable seedbed for grasses. The combination of removing shrubs, cultivation, sloping gully banks, mulching, and favorable weather conditions during this period, resulted in a good stand of grass on the watersheds (figs. 16, 17, and 18).

VEGETATION

One year after treatment, vegetation was measured by the line interception method[5/] (tables 2 and 3). Because Boer and Lehmann lovegrasses are bunchgrasses, the ground cover is not complete. However, bare areas are small and are not continuous. The grass cover is sufficient to be an important factor in protecting the ground surface from raindrop splash.

SEDIMENT PRODUCTION

Sediment rates from the untreated watersheds were lower from 1953 to 1959 than from 1932 to 1941. Sediment rates from the treated watersheds, however, have been almost negligible (table 4). Apparently, the mulch and grasses are effectively checking erosion and sediment movements. Seasonal sediment rates are shown in table 11, appendix.

5/ Canfield, R. H. Sampling vegetation by the line interception method. U. S. Forest Serv. Southwest. Forest and Range Expt. Sta. Res. Note 4, 27 pp., illus. 1942. [Processed.]

Figure 14. --Fence line between watershed numbers 2 and 3 showing treatment with hardware-cloth checks in watershed number 3. Picture taken April 1936, 2 years after checks were installed.

Figure 15. --Same photopoint as figure 14 taken in June 1950. Note that the change in vegetation immediately to the left of the fence was almost negligible.

Figure 16. --North-facing slope of Summit watersheds showing parts of watershed numbers 6 and 7. May 1936.

Figure 17. --Repeat of figure 16 after shrub removal and seeding. Watershed number 6 (left) is in original cover. September 1960.

Figure 18. --Boer and Lehmann lovegrasses established in watershed number 4. The canopy formed by these bunchgrasses has helped to stabilize the area.

Table 2. --Basal area of perennial grasses on experimental watersheds in 1954

Grass species	Seeded watersheds[1]				Unseeded watersheds		
	No. 1	No. 4	No. 5	No. 7	No. 3[2]	No. 2[3]	No. 6[3]
	Line intercept basal area in percent						
Lehmann lovegrass	0.23	0.33	0.38	0.11	0	0	0
Boer lovegrass	.08	.05	.10	.06	0	0	0
Three-awn grasses	0.11	.12	.06	0	.03	.04	T
Slender grama	.06	0	0	0	.10	.01	0
Side-oats grama	.13	.01	.06	.01	0	.02	.10
All others	.01	0	0	.08	.04	0	.02
Total	.62	.51	.60	.26	.17	.07	.12

[1] Grass seeded in 1953. Before grass was sowed, woody plant cover was cut, roots grubbed out, gully banks sloped, and gullies filled with cut plant material.

[2] Hardware cloth checks placed on slopes in 1934.

[3] Fenced 1925, ungrazed.

Table 3. --Crown cover of shrubs and forbs on experimental watersheds in 1954

Species	Watershed						
	No. 1[1]	No. 4[1]	No. 5[1]	No. 7[1]	No. 3[2]	No. 2[3]	No. 6[3]
	Crown intercept in percent						
Close crowned shrubs:							
Shrub live oak	0	0	0	0	0	0	14.65
True mountainmahogany	0	0	0	0	0	0	7.70
Hoary yucca	0	0	0	0	.98	2.50	.39
Desert shrubs:							
Jojoba	0	0	0	0	3.24	.24	0
Catclaw acacia	0	0	0	0	1.37	4.81	0
Fremont wolfberry	0	0	0	0	1.02	0	0
Mescat acacia	0	0	0	0	8.78	10.06	2.07
Half shrubs:							
Wright buckwheat	0	0	0	0	5.04	4.79	7.14
False-mesquite	0	0	0	0	6.01	4.20	.09
Littleleaf krameria	0	0	0	0	1.38	1.39	.78
Cacti:							
Opuntia spp.	0	0	0	0	.99	.97	0
Forbs:							
Spurge and globemallow	.57	.67	.13	1.41	.42	.70	.59
All others:	0	0	0	0	1.07	0	3.22
Total	.57	.67	.13	1.14	30.30	29.66	36.63

[1] Grass planted in 1953. Prior to sowing grass, woody plant cover was cut, roots grubbed out, gully banks sloped, and gullies filled with cut plant material.

[2] Hardware cloth checks placed on slopes in 1934.

[3] Fenced 1925, ungrazed.

The untreated watershed number 2 showed proportionally less sediment during the 1953-59 period than the other untreated watersheds (table 4). This watershed faces south as does watershed number 8, and both of these watersheds had proportionally less sediment in this period than did north-facing watersheds, numbers 6 and 9. A possible explanation is that soils are shallow on the south-facing watersheds, thus limiting erosion. Also, most of the available sediment may have been moved in the earlier periods, and gullies were stabilizing naturally. Future measurements will determine whether the decreased sediment yields measured since 1953 are a normal pattern on these watersheds or whether yields will increase with higher precipitation.

Table 4. --Sediment rates from the experimental watersheds for the periods 1932-41 and 1953-59

Watershed Number	Watershed treatment	Aspect	Basal area of grasses in 1954	Average annual soil loss	
				1932-41	1953-59
			Percent	Tons per square mile per year	
1	Fenced 1925 Seeded 1953	South	0.62	4,176	16
4	Fenced 1925 Seeded 1953	South	.51	2,164	31
5	Fenced 1925 Seeded 1953	North	.60	3,367	22
7	Fenced 1925 Seeded 1953	North	.26	4,970	21
3	Fenced 1925 Mechanically treated 1934	South	.17	2,278	10
2	Fenced 1925 Original cover	South	.07	7,729	575
6	Fenced 1925 Original cover	North	.12	5,525	3,623
8	Unfenced Original cover	South	--	4,743	1,102
9	Unfenced Original cover	North	--	12,785	6,115

STORM RUNOFF

Since cover conversion, storm runoff has been lower on all watersheds. Storm runoff results primarily from summer storms. Control of sediment is largely associated with decreased surface runoff. Surface runoff decreased on the watersheds that were seeded. Accordingly, sediment could be expected to decrease as storm runoff was controlled. That such relations did hold is shown in table 5. Subsurface flow was not measured on the watersheds, consequently decreased water yields are related to decreased storm runoff or surface flow. Seasonal storm runoff is shown in table 12, appendix.

AREAL AVERAGE INFILTRATION PROTECTION PERIOD

Surface runoff results from the portion of storms that exceed the infiltration capacity of the soil. Between 1932 and 1941 areal average infiltration

Table 5.--Storm runoff from the experimental watersheds for the periods 1932-41 and 1953-59

Watershed Number	Watershed treatment	Aspect	Basal area of grasses in 1954	Average annual surface runoff	
				1932-41	1953-59
			Percent	Inches	Inches
1	Fenced 1925 Seeded 1953	South	0.62	0.896	0.021
4	Fenced 1925 Seeded 1953	South	.51	.550	.025
5	Fenced 1925 Seeded 1953	North	.60	.482	.029
7	Fenced 1925 Seeded 1953	North	.26	.394	.017
3	Fenced 1925 Mechanically treated 1934	South	.17	.260	.018
2	Fenced 1925 Original cover	South	.07	.396	.069
6	Fenced 1925 Original cover	North	.12	.273	.192
8	Unfenced Original cover	South	--	1.064	.435
9	Unfenced Original cover	North	--	.667	.386

capacities were computed for runoff-producing storms for each watershed.[6/] The method is based on amount of storm runoff and rainfall intensity; assumes all parts of a watershed contribute runoff; treats surface runoff in a given storm as rainfall excess; and describes average conditions for a watershed. It is not infiltrometer data.

Areal average infiltration capacities for the 25 runoff-producing storms between 1932-41 were plotted by years to check for increased or decreased infiltration resulting from treatments. Infiltration capacities, averaged for the seven protected watersheds and for the two watersheds open to grazing, were essentially parallel. There was no significant difference in slope of the regression lines for the 10-year period.

For the seeding period, 1953-59, 21 storms produced runoff. Areal average infiltration capacities for the 4 seeded watersheds (Nos. 1, 4, 5, and 7) was 2.55 inches per hour compared to 2.14 inches per hour for

6/ Horton, Robert E., and Richard Van Vliet. Determination of areal average infiltration-capacity from rainfall and runoff data. U. S. Dept. Agr. Office of Land Use Coordination Flood Control. 47 pp., illus. 1940. [Processed.]

the 4 watersheds with original cover. Prior to seeding, infiltration rates were similar, being 1.84 for watershed numbers 1, 4, 5, and 7; and 1.82 for watershed numbers 2, 6, 8, and 9. When each storm was considered as a replication and each watershed as a separate treatment, an analysis of variance comparing the seeded and the unseeded watersheds resulted in a highly significant "F" value (69.3).

Areal average infiltration capacities for the watershed with hardware-cloth checks (No. 3) prior to treatment averaged 1.58 $\pm$ 0.29 inch per hour for 5 storms compared to 1.69 $\pm$ 0.27 inch per hour for the adjacent untreated watershed number 2. After stabilization, infiltration on watershed number 3 increased to 2.46 $\pm$ 1.01 inches compared to 2.26 $\pm$ 0.91 inch per hour on watershed number 2. This difference is also statistically significant. Thus, both cover conversion and hardware-cloth checks increased average areal infiltration capacities. Increased infiltration in turn decreased the surface runoff that carried sediment from the slopes.

STORM RUNOFF AND SEDIMENT PRODUCTION

During the seeding period, 1953-59, precipitation was lower than during the calibration periods, 1932-41. Consequently, analysis of covariance was used to make the periods comparable. Average values for the four watersheds converted to grass were compared with average values for four untreated watersheds. Regressions for sediment rates and surface runoff, before and after treatment are shown in figure 19. Both decrease in sediment and storm runoff are statistically significant.

Storm runoff and sediment rates for the watershed with hardware-cloth checks were compared with the adjacent untreated watershed before and after treatment. The regressions are shown in figure 20. These decreases in storm runoff and sediment rates are also statistically significant. Covariance analysis cannot adjust entirely for differences in precipitation between the before and after periods. The statistical significance is based on the data available. Precipitation similar to the pretreatment period may occur during future measurements.

Analysis of these regressions lead to one conclusion: a change in surface condition that increases infiltration capacities, whether by plant cover or mechanical stabilization, results in decreased surface runoff, which in turn reduces sediment.

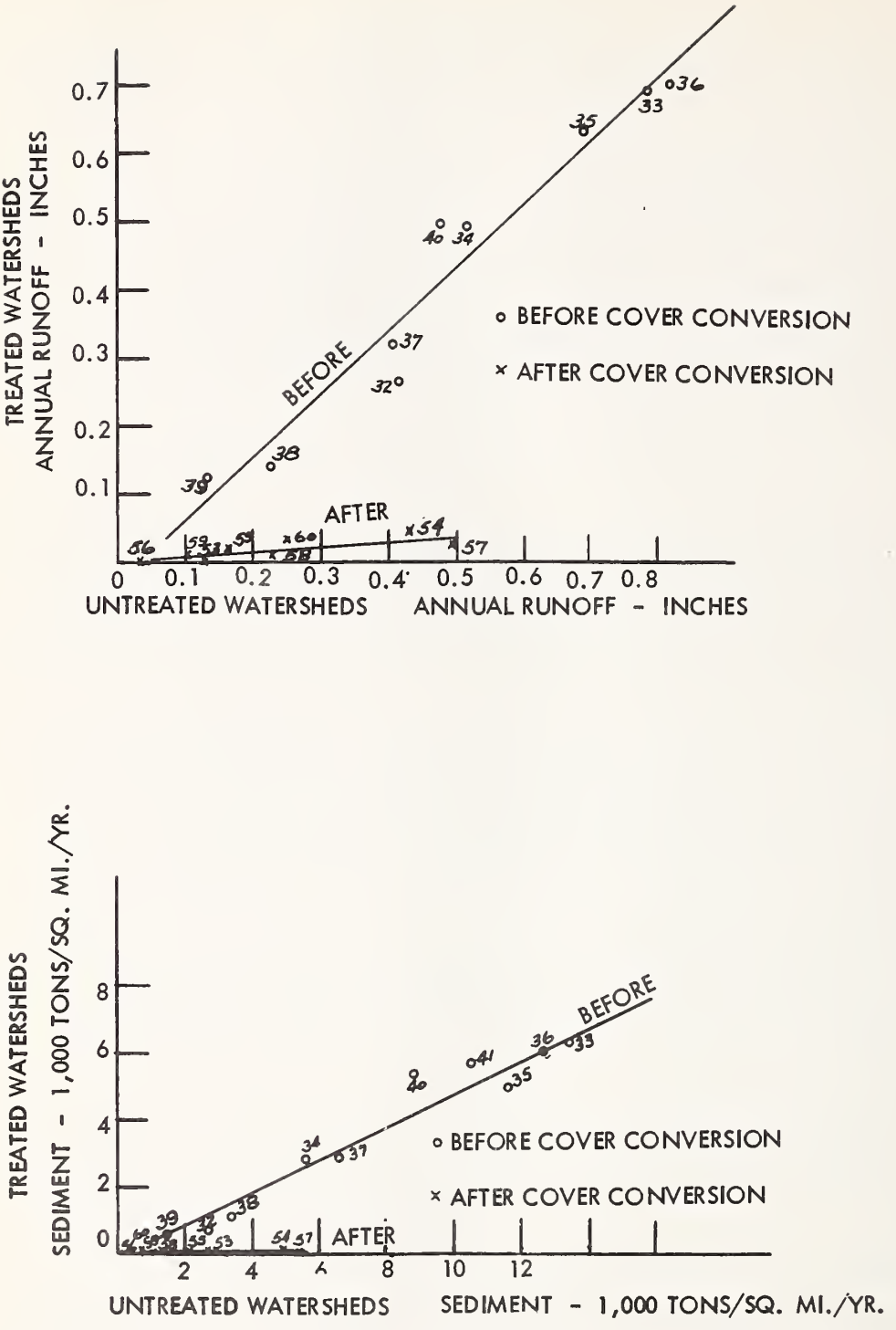

Figure 19. --Regression of storm runoff and sediment rates before and after cover conversion.

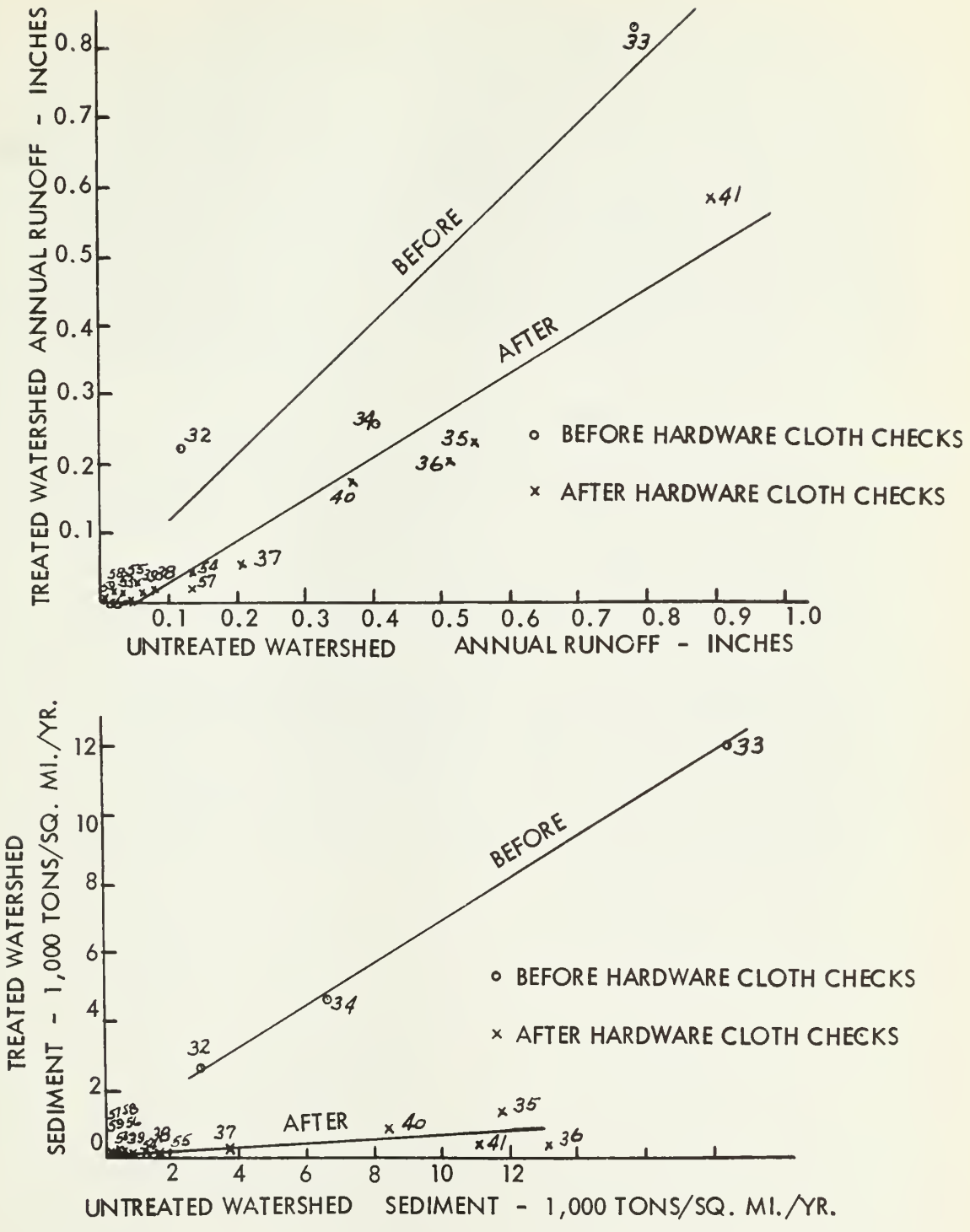

Figure 20. --Runoff and sediment rates before and after placement of hardware cloth checks.

CONTROL OF EROSION BY VEGETATION

The plant cover present on the experimental watersheds at the inception of the study was not effectively controlling erosion. First sediment measurements were higher than the average for Salt River above Roosevelt Dam. Sediment rates continued high under the natural cover, but decreased following conversion. Since the cover conversion included planting grass after cutting woody plants, grubbing out roots, sloping gully banks, and filling gullies with cut plant material, it is not possible to isolate the effect of plant cover. However, the decreased sediment following cover conversion indicates that the area is capable of producing and maintaining an adequate plant cover to control erosion under conditions characteristic of the area since 1953. Other methods, such as hardware-cloth checks placed in watershed number 3 have also decreased erosion. But in an area where plants can control erosion as well as furnish forage, maintenance and improvement of vegetation is a desirable type of land management.

SUMMARY AND CONCLUSIONS

Observations and measurements to date permit the following conclusions relative to the management of granitic watersheds in the lower chaparral zone:

1. Intense summer thunderstorms are characteristic of Arizona. Where the plant cover is sparse, and infiltration capacity low, surface runoff may be high. Surface flows carry considerable sediment, deepen channels and generally increase erosion. To control erosion, management must be directed toward reduction of surface runoff.

2. Surface runoff and erosion were reduced, and a perennial grass cover was established by cutting woody vegetation and grubbing its roots, sloping steep gully sides, placing cut brush in gully channels, and then seeding to Boer and Lehmann lovegrasses.

3. Hardware-cloth checks placed on the contour also reduced erosion, but did not produce additional vegetation. Most surface runoff was produced during summer.

APPENDIX

COMMON AND BOTANICAL NAMES OF PLANTS FOUND ON SUMMIT WATERSHEDS

Botanical Name	Common Name
Principal Grasses:	
Aristida arizonica Vasey	Arizona three-awn
A. divaricata Humb. of Bonpl.	Poverty three-awn
A. purpurea Nutt.	Purple three-awn
Bouteloua chondrosioides (H. B. K.) Benth.	Sprucetop grama
B. curtipendula (Michx.) Torr.	Side-oats grama
B. filiformis (Fourn.) Griffiths	Slender grama
Eragrostis chloromelas Steud.	Boer lovegrass
E. lehmanniana Nees	Lehmann lovegrass
Muhlenbergia porteri Scribn.	Bush muhly
Sitanion hystrix (Nutt.) J. G. Smith	Bottlebrush squirreltail
Stipa speciosa Trin. & Rupr.	Desert needlegrass
Trichachne californica (Benth.) Chase	Cottontop
Forbs:	
Euphorbia spp.	Spurge
Sphaeralcea spp.	Globemallow
Half Shrubs:	
Calliandra eriophylla Benth.	False-mesquite
Eriogonum wrightii Torr.	Wright buckwheat
Krameria grayi Rose & Painter	Grays krameria
K. parvifolia Benth.	Littleleaf krameria

Botanical Name	Common Name
Cacti:	
Carnegia gigantea (Engelm.)	Saguaro
Echinocereus engelmanni	Engelmann echinocereus
Opuntia phaeacantha Engelm.	--
O. versicolor Engelm.	Cane cholla
Shrubs:	
Acacia constricta Benth.	Mescat acacia
A. greggii A. Gray	Catclaw acacia
Celtis pallida Torr.	Spiny hackberry
Cercidium floridum Benth.	Blue paloverde
C. microphyllum (Torr.) Rose & Johnston	Yellow paloverde
Cercocarpus montanus Raf.	True mountainmahogany
Condalia obtusifolia (Hook.) Weberb.	Lotebush condalia
Dasylirion wheeleri S. Wats.	Wheeler sotol
Gutierrezia sarothrae (Pursh) Britt. & Rusby	Broom snakeweed
Juniperus monosperma (Engelm.) Sarg.	One-seed juniper
Lycium fremontii A. Gray	Fremont wolfberry
Nolina microcarpa S. Wats.	Sacahuista
Quercus turbinella Greene	Shrub live oak
Rhus ovata S. Wats.	Sugar sumac
R. trilobata Nutt.	Skunkbush
Simmondsia chinensis (Link) Schneid.	California jojoba
Yucca schottii Engelm.	Hoary yucca

Table 6. --Seasonal and annual precipitation on the experimental watersheds

Year	Winter (October through May)	Summer (June through September)	Total
	Inches	Inches	Inches
1926-27	13.36	6.93	20.29
1927-28	13.15	3.35	16.50
1928-29	8.92	6.56	15.48
1929-30	8.00	8.68	16.68
1930-31	6.74	8.68	15.42
1931-32	14.89	4.00	18.89
1932-33	10.36	8.70	19.06
1933-34	5.04	3.26	8.30
1934-35	10.82	6.48	17.30
1935-36	9.92	7.12	17.04
1936-37	11.62	5.04	16.66
1937-38	5.71	2.96	8.67
1938-39	6.05	4.66	10.71
1939-40	5.94	6.77	12.71
1940-41	24.76	4.75	29.51
1941-42	10.62	4.45	15.07
1946-47	9.63	3.60	13.23
1947-48	5.55	4.40	9.95
1948-49	9.10	5.34	14.44
1949-50	6.30	6.25	12.55
1950-51	6.41	10.29	16.70
1951-52	13.97	3.67	17.64
1952-53	8.32	6.90	15.22
1953-54	8.00	8.52	16.52
1954-55	2.94	9.11	12.05
1955-56	4.99	3.56	8.55
1956-57	8.63	6.95	15.58
1957-58	11.10	7.45	18.55
1958-59	4.58	5.83	10.41
Averages	9.15	6.01	15.16

Table 7. --Rates of sediment production and rainfall amounts for the experimental watersheds by seasons, 1931-41

Season	Watersheds 1, 2, 3, 4					Watersheds 5, 6, 7				Watershed 8		Watershed 9	
	Rain	Sediment rate on--				Rain	Sediment rate on--			Rain	Sediment rate	Rain	Sediment rate
		1	2	3	4		5	6	7				
	Inches	Tons per square mile				Inches	Tons per square mile			Inches	Tons per square mile	Inches	Tons per square mile
Winter 1931-32	14.89	220	2,437	1,809	444	14.89	791	1,062	1,221	14.89	816	14.89	2,846
Summer 1932	4.00	74	459	807	0	4.02	0	0	0	4.20	1,254	4.16	453
Winter 1932-33	10.36	257	1,708	1,106	291	11.17	206	10	14	11.16	247	10.85	214
Summer 1933	8.70	5,679	16,726	10,994	6,245	9.24	5,757	8,689	6,883	8.91	12,739	8.76	14,547
Winter 1933-34	5.04	647	869	2,466	56	5.45	44	795	167	5.93	485	5.35	365
Summer 1934	3.26	3,749	5,738	2,247	1,263	3.44	2,467	4,222	3,109	2.54	2,639	3.42	7,480
Winter 1934-35	10.72	276	177	0	14	11.70	0	13	0	11.44	187	10.77	0
Summer 1935	6.48	4,199	11,524	1,383	1,096	6.59	5,235	9,350	9,131	6.91	4,305	6.55	21,193
Winter 1935-36	9.92	956	434	0	42	10.49	253	667	500	10.27	344	9.81	2,393
Summer 1936	7.12	5,532	12,066	346	2,276	7.59	5,978	8,819	8,479	7.53	5,878	7.50	19,821
Winter 1936-37	11.19	404	83	23	0	12.49	79	265	402	12.37	638	12.24	1,007
Summer 1937	5.04	2,757	3,582	300	1,027	5.44	2,436	2,603	4,552	5.60	5,692	5.60	12,527
Winter 1937-38	5.71	662	217	0	83	6.25	190	91	694	6.38	915	6.39	2,670
Summer 1938	2.96	1,308	915	0	239	3.23	158	1,036	1,127	2.93	1,023	3.31	6,860
Winter 1938-39	5.83	239	60	0	0	6.47	0	52	28	6.32	95	6.31	353
Summer 1939	4.66	1,404	767	23	56	4.85	114	106	405	4.72	836	4.73	3,873
Winter 1939-40	5.94	0	0	0	0	6.52	0	0	0	6.52	0	6.80	0
Summer 1940	6.53	4,609	8,437	857	4,996	7.16	6,610	7,765	5,490	7.27	4,209	7.10	15,106
Winter 1940-41	24.76	6,660	8,495	254	2,787	26.70	1,506	6,913	4,552	26.30	3,563	26.48	9,802
Summer 1941	4.75	2,124	2,598	166	722	4.93	1,847	2,789	2,948	4.77	1,561	4.90	6,337
Average annual	15.79	4,176	7,729	2,278	2,164	16.86	3,367	5,525	4,970	16.70	4,743	16.59	12,785
Average winter	10.44	1,032	1,448	566	372	11.21	307	987	758	11.16	729	10.99	1,965
Average summer	5.35	3,144	6,281	1,712	1,792	5.65	3,060	4,538	4,212	5.54	4,014	5.60	10,820

Table 8. --Sediment production rates resulting from the 13 maximum storms and for the winter of 1940-41 on the experimental watersheds

Date	Rainfall (Average of 4 areas)	Sediment production in watersheds--								
		1	2	3	4	5	6	7	8	9
	Inches	Tons per square mile								
August 1, 1933	1.66	1,029	7,296	3,089	2,914	3,353	3,561	1,082	7,182	5,581
September 7-9, 1933	3.37	2,389	5,163	4,057	1,971	1,518	3,328	3,636	3,587	7,203
July 20, 1934	.99	1,396	1,592	1,752	721	443	1,191	6,217	867	2,418
August 3, 1934	.99	1,801	2,819	426	319	1,740	2,305	1,721	1,224	4,961
August 1, 1935	1.75	1,837	5,594	760	486	2,167	4,933	4,510	2,503	12,214
September 1, 1935	1.06	1,764	5,351	622	611	3,005	4,222	4,330	1,003	6,825
August 25, 1936	.86	2,022	4,483	219	1,027	2,562	3,678	4,469	1,980	6,372
September 21, 1937	1.69	1,397	3,322	300	902	2,341	2,590	4,524	3,818	10,804
July 16-17, 1940 [1]	1.43	1,654	3,213	360	1,676	1,385	2,448	2,093	1,166	5,354
August 13, 1940	1.14	1,066	4,073	498	3,053	4,991	3,709	1,832	2,258	5,591
August 8, 1941	1.42	911	1,327	134	389	1,404	1,779	2,226	1,176	3,758
September 27, 1941	1.92	1,066	1,160	32	333	443	984	694	384	2,453
Total for 13 maximum storms	18.28	18,332	45,393	12,249	14,402	25,352	34,728	37,334	27,148	73,534
Total for 10 years of summer storms	54.97	31,435	62,812	17,123	17,920	30,602	45,379	42,124	40,136	108,197
Total for 1940-41 winter storms	25.76	6,660	8,495	254	2,787	1,506	6,913	4,552	3,563	9,802
		Percent								
13 maximum storms / Total summer storms	33.3	58.3	72.3	71.5	80.4	82.8	76.5	88.6	67.6	68.0
1940-41 winter storms / Total winter storms	23.8	64.5	58.7	4.5	75.0	49.1	70.1	60.1	48.9	49.9

[1] Two storms, but sediment was not measured until after second storm.

Table 9.--Rainfall and storm runoff by seasons, 1931-41, for the experimental watersheds

Season	Watersheds 1, 2, 3, 4 (South slope, ungrazed)					Watersheds 5, 6, 7 (North slope, ungrazed)				Watershed 8 (South slope, grazed)		Watershed 9 (North slope, grazed)	
	Rainfall	Storm runoff on--				Rainfall	Storm runoff on--			Rainfall	Storm runoff	Rainfall	Storm runoff
		1	2	3	4		5	6	7				
	Inches												
Winter 1931-32	14.89	0.322	0.107	0.166	0.280	14.89	0.231	0.109	0.117	14.89	0.796	14.89	0.353
Summer 1932	4.00	.095	.015	.055	.034	4.02	.001	0	.001	4.20	.249	4.16	.027
Winter 1932-33	10.36	.103	.060	.080	.086	11.17	.039	.013	.022	11.16	.148	10.85	.039
Summer 1933	8.70	1.010	.718	.749	.823	9.24	.393	.273	.310	8.91	1.170	8.76	.655
Winter 1933-34	5.04	.278	.120	.110	.150	5.45	.163	037	.038	5.93	.530	5.35	.052
Summer 1934	3.26	.512	.286	.147	.310	3.44	.281	.205	.231	2.54	.561	3.42	.273
Winter 1934-35	10.72	.042	.013	0	.059	11.70	.044	.012	.007	11.44	.174	10.77	.002
Summer 1935	6.48	.978	.534	.230	.433	6.59	.486	.320	.478	6.91	.898	6.55	.780
Winter 1935-36	9.92	.176	.041	.014	.075	10.49	.188	.056	.086	10.27	.313	9.81	.113
Summer 1936	7.12	.919	.467	.190	.359	7.59	.523	.369	.500	7.53	1.021	7.50	.892
Winter 1936-37	11.19	.043	.028	.017	.062	12.49	.131	.035	.045	12.37	.227	12.24	.059
Summer 1937	5.04	.460	.173	.042	.160	5.44	.182	.071	.202	5.60	.663	5.60	.369
Winter 1937-38	5.71	.056	.028	.007	.033	6.25	.054	.015	.031	6.38	.194	6.39	.074
Summer 1938	2.96	.165	.048	.006	.046	3.23	.083	.035	.103	2.93	.264	3.31	.200
Winter 1938-39	5.83	.044	.012	.008	.022	6.47	.042	.007	.043	6.32	.083	6.31	.043
Summer 1939	4.66	.211	.049	.002	.041	4.85	.061	.004	.043	4.72	.181	4.73	.161
Winter 1939-40	5.94	0	.004	.002	.011	6.52	.030	.005	.001	6.52	.013	6.80	0
Summer 1940	6.53	.836	.364	.177	.420	7.16	.367	.230	.326	7.27	.696	7.10	.580
Winter 1940-41	24.76	2.186	.643	.436	1.730	26.70	1.140	.662	.973	26.30	1.986	26.48	1.517
Summer 1941	4.75	.523	.255	.158	.365	4.93	.386	.272	.381	4.77	.474	4.90	.481
Average annual	15.79	.896	.396	.260	.550	16.86	.482	.273	.394	16.70	1.064	16.59	.667
Average winter	10.44	.325	.106	.084	.251	11.21	.206	.095	.136	11.16	.446	10.99	.225
Average summer	5.35	.571	.291	.176	.299	5.65	.276	.178	.258	5.54	.618	5.60	.442
	Percent												
Average annual	--	5.67	2.51	1.65	3.48	--	2.86	1.62	2.34	--	6.37	--	4.02
Average winter	--	3.11	1.02	.80	2.40	--	1.84	.85	1.21	--	4.00	--	2.05
Average summer	--	10.67	5.44	3.29	5.59	--	4.88	3.15	4.57	--	11.16	--	7.89

Table 10. --Storm runoff resulting from the 13 maximum summer storms and for the winter of 1940-41, Summit watersheds

Date	Rainfall (Average of 4 areas)	Storm runoff in watersheds--								
		1	2	3	4	5	6	7	8	9
	Inches	Inches								
August 1, 1933	1.66	0.281	0.334	0.220	0.239	0.124	0.075	0.095	0.331	0.248
September 7-9, 1933	3.37	.432	.222	.297	.351	.188	.129	.144	.557	.334
July 20, 1934	.99	.174	.109	.118	.148	.093	.067	.067	.234	.095
August 3, 1934	.99	.256	.129	.025	.111	.140	.104	.117	.261	.176
August 1, 1935	1.75	.450	.266	.100	.196	.242	109	.236	.505	.499
September 1, 1935	1.06	.421	.242	.128	.195	.202	.206	.228	.211	.226
August 25, 1936	.86	.393	.218	.103	.153	.184	.140	.216	.308	.250
September 21, 1937	1.69	.284	.145	.041	.130	.152	.063	.187	.416	.265
July 16-17, 1940 [1]	1.43	.356	.159	.067	.158	.096	.069	.098	.224	.190
August 13, 1940	1.14	.332	.154	.107	.198	.182	.122	.157	.294	.218
August 8, 1941	1.42	.303	.181	.131	.250	.181	.145	.214	.313	.013
September 27, 1941	1.92	.177	.067	.026	.098	.174	.119	.159	.153	.282
Total for 13 maximum storms	18.28	3.859	2.226	1.363	2.227	1.958	1.348	1.918	3.807	2.796
Total for 10 years of summer storms	54.97	5.709	2.910	1.756	2.992	2.704	1.780	2.575	6.177	4.418
Total for winter storms in 1940-41	25.76	2.186	.643	.436	1.730	1.140	.662	.973	1.986	1.517
Total for 10 years of winter storms	108.39	3.251	1.056	.843	2.508	2.062	.950	1.363	4.464	2.252
		Percent								
13 maximum storms / Total summer storms	33.3	67.6	76.5	77.6	74.4	70.8	75.7	74.5	61.6	63.3
1940-41 winter storms / Total winter storms	23.8	67.2	60.9	51.7	69.0	55.3	69.7	71.4	44.5	67.4

[1] Two storms, but water was not measured until after second storm.

Table 11. --Sediment and rainfall by seasons on the experimental watersheds, 1953-59

Season	Rainfall	Sediment rate on watersheds--								
		1	2	3	4	5	6	7	8	9
	Inches	Tons per square mile								
Summer 1953	6.90	35	291	0	0	0	3,977	0	960	7,821
Winter 1953-54	8.00	0	0	0	0	0	61	0	0	327
Summer 1954	8.52	14	1,220	26	52	60	6,100	52	1,392	11,660
Winter 1954-55	2.94	14	270	9	130	48	29	48	80	38
Summer 1955	9.11	35	1,447	22	26	30	3,401	32	934	2,915
Winter 1955-56	4.99	0	0	0	0	0	0	0	0	0
Summer 1956	3.56	17	338	11	13	15	836	13	360	1,612
Winter 1956-57	8.63	0	42	0	0	0	0	0	0	0
Summer 1957	6.95	[1] T	333	T	T	T	6,442	T	2,656	11,708
Winter 1957-58	11.10	0	0	0	0	0	0	0	0	0
Summer 1958	7.45	T	T	T	T	T	1,859	T	246	3,470
Winter 1958-59	4.58	0	0	0	0	0	0	0	0	0
Summer 1959	5.83	T	83	0	T	T	1,742	T	733	1,408
Winter 1959 [2]	6.95	0	0	0	0	0	913	0	352	1,849
Average annual	13.64	16	575	10	31	22	3,623	21	1,102	6,115
Average summer	6.90	14	530	9	13	15	3,480	14	1,040	5,799
Average winter	6.74	2	45	1	19	7	143	7	62	316

[1] Trace.

[2] Only part of year.

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Table 12. --Rainfall and storm runoff by seasons on the experimental watersheds, 1953-59

Season	Rainfall	Storm runoff on watersheds--								
		1	2	3	4	5	6	7	8	9
	Inches	- - - - - - - - - - - - - -				Inches	- - - - - - - - - - - - - -			
Summer 1953	6.90	0.014	0.042	0.001	0.020	0.014	0.099	0.002	0.196	0.188
Winter 1953-54	8.00	.004	.023	.016	.015	.047	.018	.016	.058	.115
Summer 1954	8.52	.037	.111	.024	.044	.043	.327	.020	.572	.506
Winter 1954-55	2.94	0	0	0	0	0	0	0	0	0
Summer 1955	9.11	.009	.061	.022	.026	.013	.095	.034	.298	.198
Winter 1955-56	4.99	.001	.013	.018	.005	0	.009	0	0	0
Summer 1956	3.56	0	.003	0	0	0	.037	0	.143	.093
Winter 1956-57	8.63	.020	.023	.013	.020	.021	.020	.014	.079	.030
Summer 1957	6.95	0	.114	.008	.009	.012	.211	.008	.687	.815
Winter 1957-58	11.10	.002	.002	[1] T	.004	.002	.015	.002	.048	.037
Summer 1958	7.45	.002	.024	.006	.005	.014	.178	.006	.270	.340
Winter 1958-59	4.58	.003	0	0	0	0	.007	0	.003	.016
Summer 1959	5.83	0	0	0	0	0	.120	0	.166	.171
Winter 1959-60 [2]	6.95	.054	.064	.019	.030	.039	.209	.016	.527	.194
Average annual	13.64	.021	.069	.018	.025	.029	.192	.017	.435	.386
Average summer	6.90	.009	.051	.009	.015	.014	.152	.010	.333	.330
Average winter	6.74	.012	.018	.009	.010	.015	.040	.007	.102	.056
		- - - - - - - - - - - - - -				Percent	- - - - - - - - - - - - - -			
Average annual		.15	.50	.13	.18	.21	1.41	.12	3.19	2.83
Average summer		.13	.74	.13	.22	.20	2.20	.14	4.83	4.78
Average winter		.18	.27	.13	.15	.22	.59	.10	1.51	.83

[1] Trace

[2] Only part of year.

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